Sound Reverberation

- In an enclosed environment sound can continue to reflect for a period of time after a source has stopped emitting sound.
- This prolongation of sound is called reverberation.
- Reverberation time (RT60) is defined as the time required for the average sound intensity in a room to decrease by 60 dB after a source stops generating sound.
- However, excessive reverberation sound causes a loss of clarity

- Sound reverberation time is affected by the size of the space and the amount of absorption coefficients of the surfaces in the space.
- A space with highly absorption surfaces will absorb the sound and stop it from reflecting back into the space, this would yield a short reverberation time.
- Reflective surfaces will reflect sound and increase the reverberation time.

Reverberation time (Sabine formula)

- Sound energy in the room depends on
  - the power of the source
  - the volume of the room
- The rate at which that energy is absorbed depends on:
  - the area and absorption coefficients of all the surfaces in the room

$$\boxed{RT = K\frac{V}{A}}$$

K – constant

V – volume of the room

A – absorption (effective surface area)

Generally, large rooms have longer reverberation times than do small rooms

$$k = \frac{4.\ln(10^{-6})}{c} \qquad c = 343 m/s \qquad k = 0.1611 s/m$$

Reverberation time (Sabine formula)

$$\left\langle I_a\left(t=T_{60}, f\right)\right\rangle=\left\langle I_a^o\left(f\right)\right\rangle e^{-T_{60}/\tau_W}=10^{-6}\left\langle I_a^o\left(f\right)\right\rangle$$

$$\left\langle I_a\left(t=T_{30}, f\right)\right\rangle=\left\langle I_a^o\left(f\right)\right\rangle e^{-T_{30}/\tau_W}=10^{-3}\left\langle I_a^o\left(f\right)\right\rangle$$

Another form of the ***Sabine equation*** is

$$\boxed{T_{60}=-\tau_W \ln\left(10^{-6.0}\right)=13.8155\,\tau_W}.$$

$$\tau_W \equiv \frac{4V}{cA},$$

characteristic time constant

Similarly, we can also show that the ***reverberation time*** T_{30} defined as the time it takes for the time-averaged sound intensity to decay to one-thousandth (10^{-3}) of its initial value is given by:

$$\boxed{T_{30}=-\tau_W \ln\left(10^{-3.0}\right)=6.9078\,\tau_W=\tfrac{1}{2}T_{60}}$$

Diffraction of Sound

- Wavefronts and rays of sound travel in straight lines, except when something gets in the way.
- Obstacles can cause sound to be changed in its direction from its original path.
- The process by which this change of direction takes place is called *diffraction*.

Diffraction and Wavelength

- Obstacles capable of diffracting (bending) sound must be large compared to the wavelength of the sound involved.
- The effectiveness of an obstacle in diffracting sound is determined by the *acoustical size* of the obstacle.
- Acoustical size is measured in terms of the wavelength of the sound.

Some Examples of Diffraction

- In figure A, the upper edge of the wall acts as a new, virtual source sending sound energy into the “shadow” zone behind the wall.

- In figure B, most of the sound energy is reflected from the wall surface, but that small portion going through the hole acts as a virtual point source, radiating a hemisphere of sound into the “shadow” zone behind the wall by diffraction.

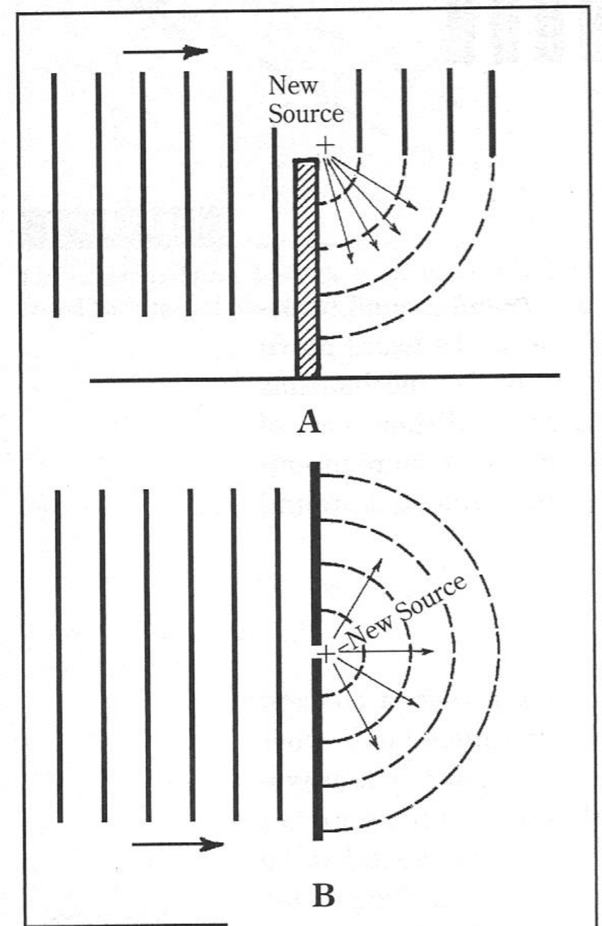


FIGURE 11-1

(A) If the brick wall is large in terms of the wavelength of the sound, the edge acts as a new source, radiating sound into the shadow zone. (B) Plane waves of sound impinging on the heavy plate with a small hole in it sets up spherical wavefronts on the other side due to diffraction of sound.

Diffraction by Large and Small Apertures

- In figure A, the arrows indicate that some of the energy in the main beam is diverted into the shadow zone.

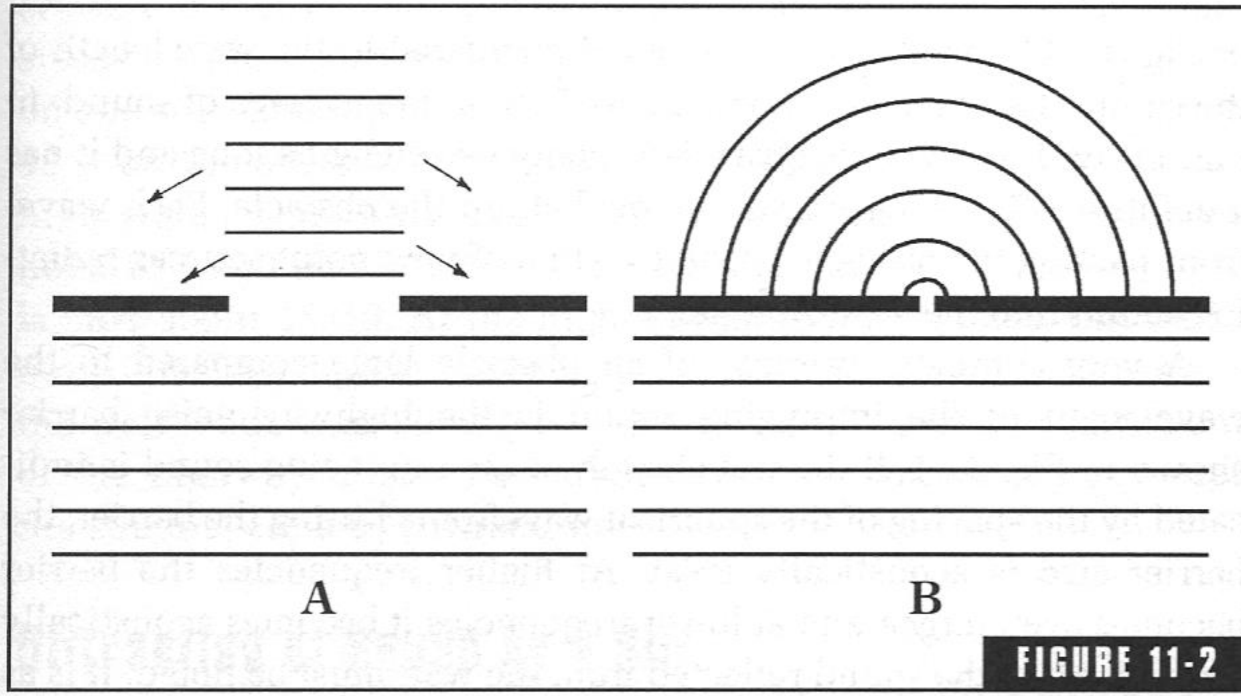
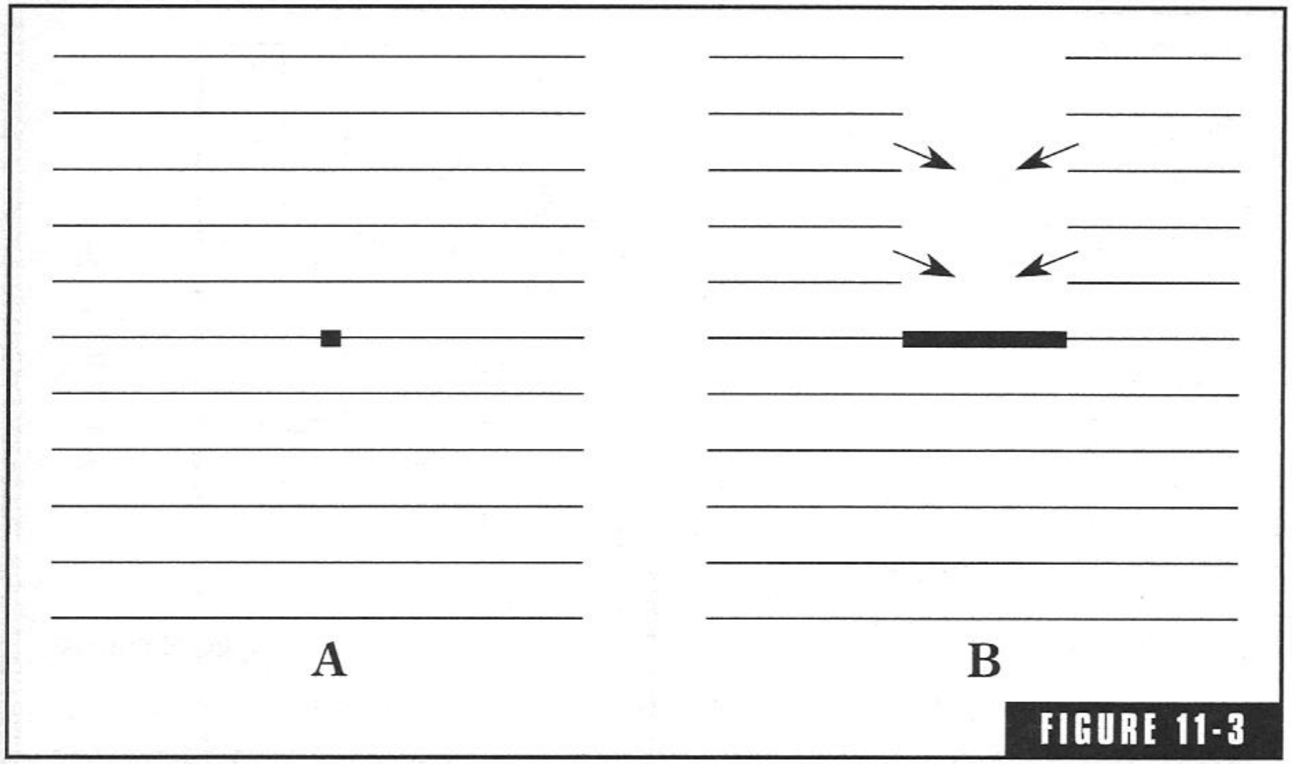


FIGURE 11-2

(A) An aperature large in terms of wavelength of sound allows wavefronts to go through with little disturbance. These wavefronts act as lines of new sources radiating sound energy into the shadow zone. (B) If the aperature is small compared to the wavelength of the sound, the small wavefronts which do penetrate the hole act almost as point sources, radiating a hemispherical field of sound into the shadow zone.

Diffraction of Sound by Obstacles

- In figure A the obstacle is so small compared to the wavelength that it has no appreciable effect on the passage of sound.



(A) An obstacle very much smaller than the wavelength of sound allows the wavefronts to pass essentially undisturbed. (B) An obstacle large compared to the wavelength of sound casts a shadow that tends to be irradiated from sources on the wavefronts of sound that go past the obstacle.

- The amount of diffraction increases with increasing wavelength and decreases with decreasing wavelength.

Refraction of Sound

- *Diffraction* is changing the direction of travel of sound by encountering sharp edges and physical obstructions.

- *Refraction* changes the direction of travel of the sound by differences in the velocity of propagation.

Refraction of Light

- The visual distortion that occurs when an object is placed in the water at an angle is due to refraction of the light waves in the denser medium.

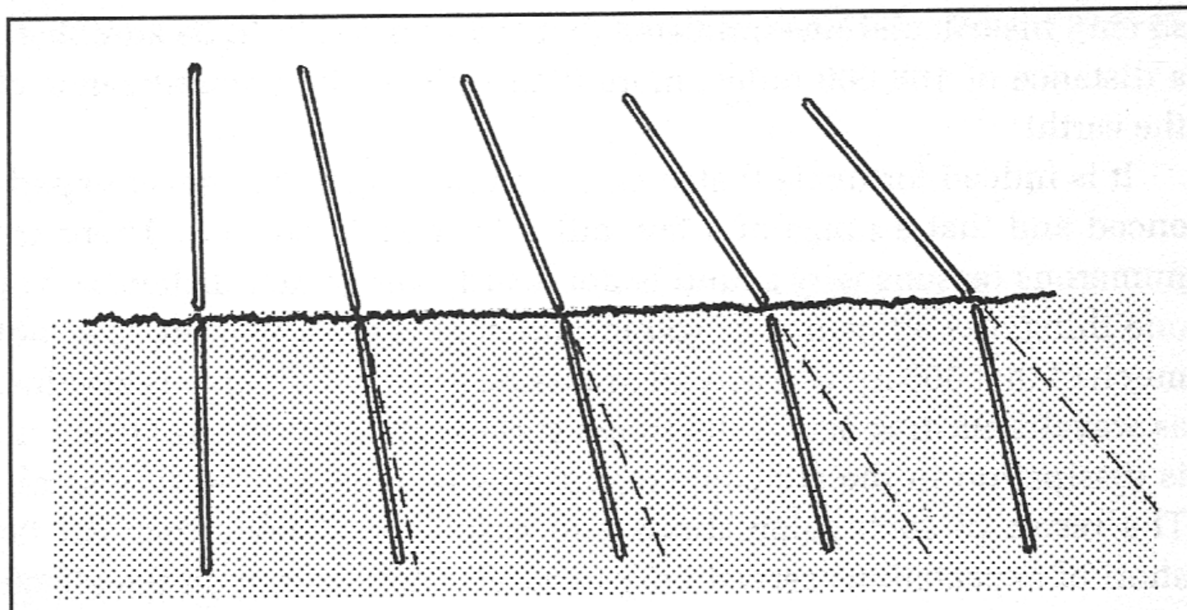


FIGURE 12-1

Touching a stick to the water surface illustrates refraction of light. Sound is another wave phenomenon that is also refracted by changes in media sound speed.

Refraction of Sound in Solids

- Sound waves traveling through materials at an angle will bend when they encounter a different material of greater or lesser density.

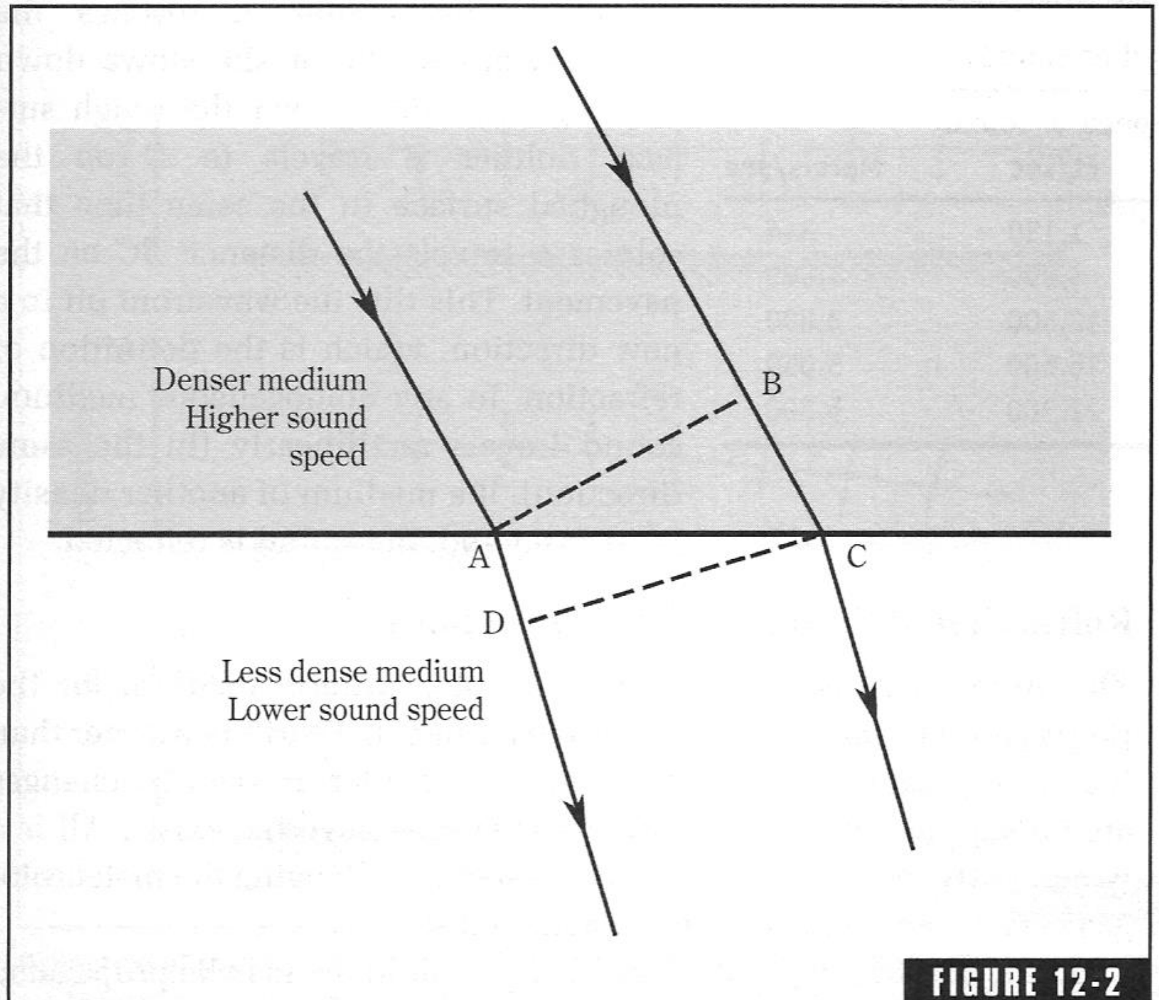
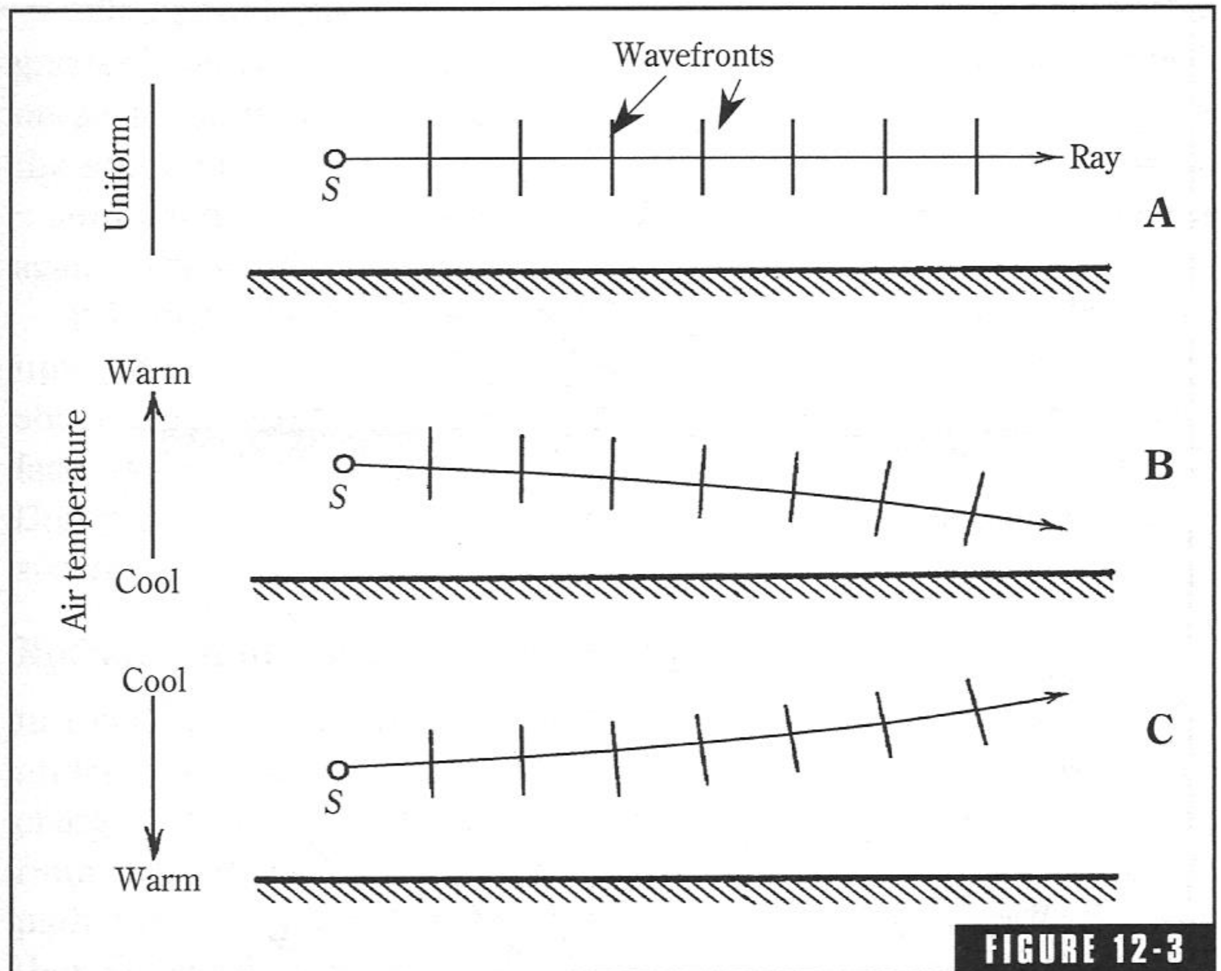


FIGURE 12-2

Rays of sound traveling from a denser medium having a certain sound speed into a less dense medium having a lower sound speed. The wavefront *AB* is not parallel to wavefront *DC* because the direction of the wave is changed due to refraction.

Refraction of Sound in the Atmosphere

- The atmosphere is anything but a stable, uniform medium for the propagation of sound.
- The diagram shows refraction due to temperature gradients.



Refraction of sound paths resulting from temperature gradients in the atmosphere; (A) air temperature constant with height, (B) cool air near the surface of the earth and warmer air above, (C) warm air near the earth and cooler air above.

Refraction of Sound in the Atmosphere

- In the absence of thermal gradients, a sound ray may be propagated rectilinearly as shown in Fig. 12-3A.
- In Fig. 12-3B a thermal gradient exists between the cool air near the surface of the earth and the warmer air above.
- This affects the wavefronts of the sound. Sound travels faster in warm air than in cool air causing the tops of the wavefronts to go faster than the lower parts.

- The thermal gradient of Fig. 12-3C is reversed from that of Fig. 12-3B as the air near the surface of the earth is warmer than the air higher up.
- In this case the bottom parts of the wavefronts travel faster than the tops, resulting in an upward refraction of the sound rays.
- A wind gradient exists in such a case that has its effect

on propagation of sound. This is not a true refraction but the effect is the same.

- Plane waves from a distant source traveling with the wind would bend the sound down toward the earth.
- Plane waves traveling against the wind will be bent upward.